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TESLA Code Modeling of a 1.3 GHz, 10 MW Multiple Beam Klystron

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Abstract: *Results of 2.5D large signal modeling of an MBK using TESLA are described. This device was successfully built and delivered to DESY in Hamburg, Germany. Comparison between measured data and code predictions are presented.*

Keywords: TESLA; EIK; MBK; beam minimum velocity; harmonics; cavity.

Introduction

TESLA is a two and a half dimensional large-signal simulation code for vacuum electron devices (specifically klystrons, extended interaction klystrons [EIKs] and multiple-beam klystrons [MBKs]). In this code, the self-consistent nonlinear interaction of electromagnetic fields with electron beams is described using three-dimensional equations of electron motion and the time-dependent field equations. Since it is a multi-frequency code, it is capable of accurately modeling the effect of higher harmonics on a device. It is also currently being extended to model the large-signal performance of MBK's. The currently available version of the code is used to model an MBK by replacing the multi-beam device by an equivalent single-beam device producing a fraction of the power equally divided among all beams. This assumes that all beams behave identically which is the ideal case. The latest beta release version of TESLA has the option of treating slow and reflected particles with a more accurate approach as opposed to the approximate approach in the previous releases. The more accurate approach allows one to include slow and reflected particles in the simulation by making use of rigorous mathematical calculations. This option in the latest version of TESLA is of particular interest for the work to be presented in this paper.

Description of device and TESLA Model

A 10 MW, 1.3 GHz multiple beam klystron, designated the VKL-8301, was successfully developed at CPI and delivered to DESY in Hamburg, Germany [1] to be used in the test accelerator for the European X-FEL. The basic advantage of the multi-beam device is a much lower operating beam voltage resulting in a more compact and less expensive modulator. This MBK has six electron beams propagating off-axis on a large bolt circle. Each beam interacts with a series of six cavities: three conventional TM_{01} mode klystron cavities, a second-harmonic cavity and two large TM_{02} mode cavities at the input and output. Regeneration was observed during initial testing of the device for high efficiency operation. By reducing the output cavity Q_e, stable, full power operation could be achieved at a slightly reduced efficiency. TESLA modeling of the device will be used to understand the origins of the regeneration for the original design parameters. This paper will present the effect of applying the more accurate approach to the test particles and how the code predicted beam minimum velocity relates to the observed effect of beam regeneration. The cavity parameters as measured during cold-test are entered as input to TESLA. Measured axial magnetic field is also input to the code.

Simulation Results

Figure 1 shows that the TESLA solution for saturated output power reaches convergence well with time. One could have stopped the simulation after 1.5 micro-second to save computer CPU time. This particular simulation uses 1800 test particles, six temporal harmonics and the default value of fractional initial velocity for which a particle is considered as "special" to use the more accurate approach for slow/reflected particles. The choices of total number of test particles and temporal harmonics in the simulation were based on the sensitivity studies as depicted in Figure 2. Although the convergence of the solution with the variation of temporal harmonics improves by increasing the number of particles from 400 (default value) to 2400, the choice of 1800 particles is an optimum for accuracy and run time. Figure 3 shows that the variation in the axial

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component of normalized particle velocity is slow or even negative at the output gap location using the more accurate approach in the simulation. These particles with negative motions though get re-accelerated at later time in RF phase and become normal. This is consistent with what was observed in real device. It is obvious from Figure 4 that the beam minimum velocity is relatively insensitive to the fractional initial velocity for which particles are treated as "special". Increasing this parameter (part_out_factor) will increase the fraction of particles to be treated more accurately but results in a longer run time. The relative insensitiveness of the beam minimum velocity to the parameter "part_out_factor" is the result of application of more accurate approach in the recent version of the code [2]. Table 1 shows that the TESLA predicted saturated output power and gain agree reasonably well with measured data, but its prediction of efficiency is higher than that of measurement.

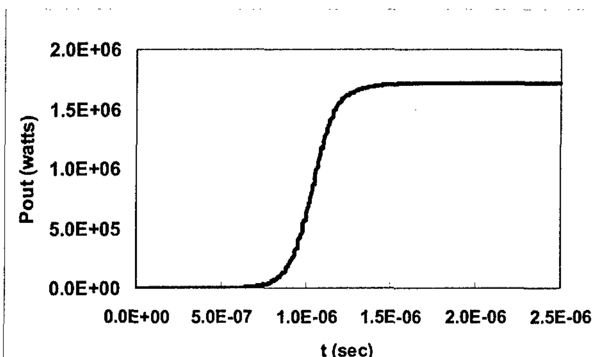

Figure 1. Convergence of TESLA solution with time at 1.3 GHz.

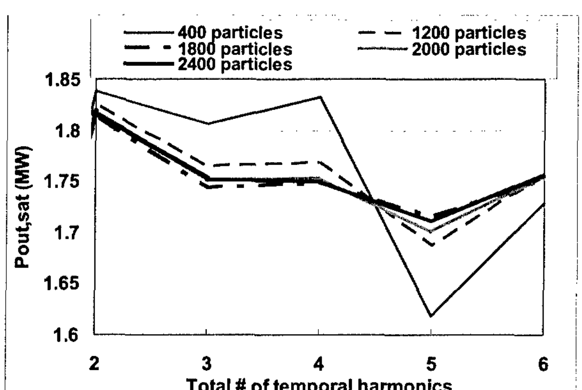

Figure 2. Variation of saturated output power with number of particles & temporal harmonics at 1.3 GHz.

References:

1. A. Balkcum et al, "Continued Operation of a 1.3 GHz Multiple Beam Klystron for TESLA", Proceedings of IVEC 2005, 20-22 April 2005.
2. T. Antonsen et al, "Simulation of Klystrons with Reflected Electrons using TESLA", Proceedings of IVEC-2005, 20-22 April 2005.

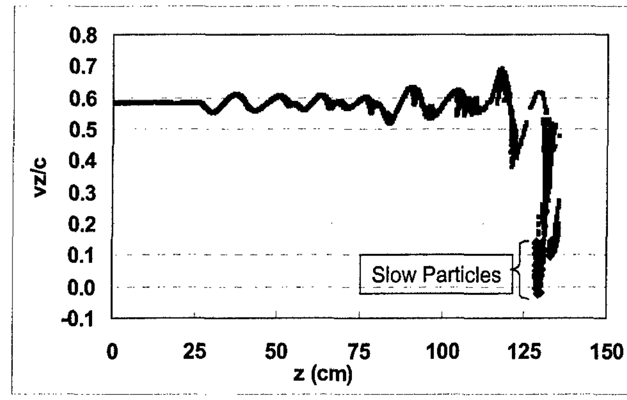

Figure 3. Variation of normalized particle velocity with axial distance at 1.3 GHz.

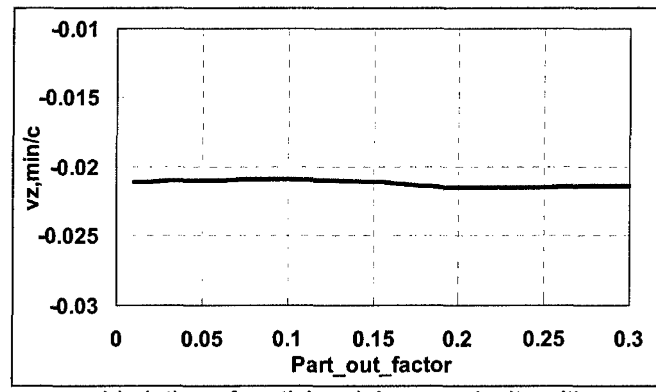

Figure 4. Variation of particle minimum velocity with fraction of initial velocity for which particles are treated "special" at a higher frequency.

	Measured	1D LS Code	TESLA
Saturated Power (MW)	10	11.03	10.66
Saturated Gain (dB)	48	46.31	46.5
Efficiency (%)	59	65.69	63.4

Table 1. Comparison among measured data, TESLA predictions and CPI 1D, LS Code predictions at 1.3 GHz with Vbeam=120KV, Ibeam=23.33A.